Distribution and Ecology of Bobcats in Ohio: Inferences from Camera Trapping Data

Undergraduate Research Thesis

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ABSTRACT

The ranges of many predators have been reduced in recent history due to hunting and the expansion of human-dominated habitats. Bobcats (*Lynx rufus)* were extirpated from Ohio by the 1850's, but are now returning to southeastern Ohio. The distribution and ecological effects of these recovering bobcat populations are just beginning to be investigated but little information is available on newly founded populations. In this study, remote motion-activated camera traps were used to record the presence of bobcats and other wildlife in southeastern Ohio. A total of 14 study sites were surveyed in 2008-2011 (by Dr. Suzanne Prange, ODNR) and 2014 (my survey). This resulted in 718 "trap nights" of data, over 4,000 photo captures of 23 animal species, and 91 detections of bobcats, including detections at three new sites in 2014. Using the full data set, I found that the number of bobcat detections per trap night was significantly greater at some sites than others (P <0.05), possibly due to land use or prey abundance differences between sites. I also tested for associations between bobcats and a common prey species (deer) and with two other predators (coyotes and foxes). My analyses did not show a relationship between any of these species and bobcat presence. I also examined associations between lunar cycle and bobcat detections, as other studies have found reduced predator activity at night when the moon is brightest and prey may be most wary of nocturnal predators. Approximately 60% of bobcat detections occurred at night (N = 55 detections) but I did not find a statistically significant effect of lunar cycle on bobcat detections. Overall, these results have implications for bobcat management within the state and provide further information on interspecific associations and bobcat activity patterns in Ohio. Further research will be essential as bobcats continue to expand their species range.

INTRODUCTION

Bobcats (*Lynx rufus*) were extirpated from the state of Ohio in the mid-1850's and were functionally absent from its ecosystems for about 150 years (Prange 2011). Their removal coincided with that of other top predators, such as pumas (*Puma concolor*), gray wolves (*Canis lupus*), and black bears (*Ursus americanus*), resulting in an absence of native terrestrial, mammalian top predators in Ohio (Laliberte and Ripple 2004). Around 2000, bobcats began to establish populations in Ohio again, making them the first of the extirpated top predators to return to their historic range in the state (Prange 2011). While larger predators such as wolves and pumas remain absent, the bobcat occupies an apex predator role in this area along with the nonnative coyote species (*Canis latrans*) (Sergio et al. 2014). Their reappearance in southern and eastern Ohio may have profound impacts on these ecological communities.

Predators are widely regarded by ecologists as important components of many ecosystems. Top-down control (predation) and bottom-up support (energy availability) both have a strong influence in shaping ecological communities (Ritchie and Johnson 2009). In the simplest three-part trophic model, predators consume prey animals, which in turn consume energy-harnessing plants (Prugh et al. 2009). Here, the absence of predators predictably leads to an increase in prey animals and a decrease in plant diversity (Terborgh and Estes 2010). However, real ecosystems typically have more complicated interactions between and across trophic levels, leading to less easily predictable outcomes from predator presence or absence (Prugh et al. 2009). There are also many known and suspected indirect effects attributed to predation, such as impacts on wildfire, disease prevalence, water quality, invasive species, and biodiversity (Estes et al. 2011).

It is important to study real, complex ecosystems to get a deeper understanding of ecological patterns and phenomena associated with predators.

Predator ecology only became a popular science in the 1950's and 60's, corresponding with a shift in public opinion from viewing predators as nuisances to considering them as vital components of communities (Sergio et al. 2014). Unfortunately, by this time predator populations were already greatly reduced in many places. Terrestrial mammalian predators have declined by over 95% in some areas of the world due to the direct and indirect effects of human expansion (Ritchie and Johnson 2009). Research has been conducted on the communities that retained all trophic levels and in communities that already lost their predators. From this research came such pivotal ideas as the Green World hypothesis (1960), Paine's keystone predators (1966), and Estes and Palmisano's insights from sea otters in the kelp forest (1974) (Sergio et al. 2014). These foundational hypotheses are still being expanded upon and many predatory species, including bobcats, are still not fully understood in their natural habitats.

However, it can be difficult to study animals that are naturally rare, solitary, and have a limited distribution in the study area. Bobcats in particular can be elusive and difficult to observe (Crowe 1975). Capturing and handling animals requires time, money, and labor and may endanger both the animal and the researcher. Noninvasive methods like scent stations, remote cameras, hair snares, scat collection, and print tracking are time and cost effective and safer for both researchers and animals (Prange 2011). The ability to gather data on rare, elusive, and ecologically important animals without physical capture is important for protecting individual animal welfare and improving data quality by lessening impact on animal behavior (Heilbrun et al. 2006). Camera trapping, the research method used for this study, is beneficial to studies of elusive carnivores because it is non-invasive but still offers direct evidence of study animals (Sunarto et al. 2013). Camera trapping has been widely documented as an acceptable method of population assessment (Moruzzi et al. 2002, Heilbrun et al. 2006, Erb 2012). Even for behavioral studies, some researchers claim that camera traps provide better data than radio telemetry (Bridges et al. 2004, Sunarto et al. 2013). With camera trapping methods we can observe animals as they move through their habitats and monitor their distribution, abundance, and activity across locations.

Very little research has been done on bobcats in southeastern Ohio. Prange (2011) studied seasonality in capturing these bobcats on camera traps (the highest detection rate was May-July) and evaluated the efficacy of track pad stations. Rose and Prange (2015) examined the diet composition of bobcats using stomach contents from dead animals and discovered that they consume eastern cottontail rabbits (*Sylvilagus floridanus*) and white-tailed deer (*Odocoileus virginianus*) most often. Anderson et al. (2014) genetically analyzed bobcats from the region and found that two populations of genetically distinct bobcats exist, one in the south and one in the east. This is thought to be because of the near-simultaneous migration of bobcats from the south (West Virginia) and the east (Pennsylvania). Both populations were, however, genetically variable and there was no indication of inbreeding or a bottleneck— common threats to small populations.

More research has been done on bobcats in other areas. Though much of their range in North America was lost during human expansion and settlement of the 18th and 19th centuries, bobcats have largely recovered and now occupy over 90% of their historic range (Laliberte and Ripple 2004). Most research has been conducted on those populations that were either never lost from an area or that recovered their populations quickly. Lovallo and Anderson (1996) used radio telemetry on Wisconsin bobcats to uncover basic bobcat biology such as home range size, range differences between males and females, and habitat selection. Heilbrun et al. (2006) found that camera traps allow researchers an alternative and, in some ways, superior method to assess bobcat populations. My research seeks to answer questions that follow from the published literature and to expand upon known bobcat ecology.

Questions

This study utilized data from bobcat camera trapping studies conducted by me in February and March 2014 and by the Ohio Department of Natural Resources, Division of Wildlife from 2008 through 2011. These studies span five years and cover all seasons, resulting in a total of 718 trap nights, over 4,000 photo captures of 23 animal species, and 91 detections of bobcats (see summary of dataset, Table 1). Study sites are geographically limited to the southeastern region of the state to correspond with known and suspected bobcat presence as suggested by sightings from the public (see map of study sites, Figure 1 and summary of study sites, Table 2) (Prange 2011). This area of Ohio lies within the Western Allegheny Plateau ecoregion and is topographically dominated by steep slopes, ridges, and valleys (Rose and Prange 2015). Farming and mining are still common, but much of the study area is dominated by oak and hickory forests present since 1850-1900 (see Table 3, summary of study site environments) (Rose and Prange 2015).

In addition to reporting on the results from the most recent camera trapping effort in 2014, I also asked broader ecological questions regarding bobcats in Ohio. These questions are:

How does the relative abundance of bobcat detections vary among sites?

As bobcats repopulate the state, they move through the landscape and may have greater abundance in some sites than in other sites. It has been suggested that bobcats inhabit some environment types more often, and that Ohio bobcats in particular are unevenly distributed within their range (Lovallo and Anderson 1996, Prange 2011). Here, I looked for patterns in the relative abundance of bobcats between study sites used these results to and statistically describe their distribution in this part of Ohio.

Are there associations between bobcats and other animal species?

Research on predator ecology shows the impact that predatory animals can have on their ecosystems. Interactions between members of ecological communities link species together and contribute to complexity and diversity (Estes et al. 2011). Prey species typically are less abundant when a predator is introduced (Sergio et al. 2014). Intraguild competition between two top predators may lead to niche separation or the domination of one predator species through competitive exclusion (Hardin 1960). Top predators are also widely believed to have a negative effect on mesopredators, those carnivores that consume prey species but may also be predated upon (Prugh et al. 2009). Top predators may have a disproportionate—in some cases, four-fold—negative effect on mesopredator abundance due to combined predation and aggression pressures from the top (Ritchie and Johnson, 2009).

For this study, analysis on interspecific associations focused on white-tailed deer *Odocoileus virginianus* (prey), coyotes *Canis latrans* (competitor), and red foxes *Vulpes vulpes* and gray foxes *Urocyon cinereoargenteus* (mesopredators). These species were selected as representatives for their relationship to bobcats because of their roles in the animal community and their significance as species of interest. Deer are the second most frequently consumed prey species of Ohio bobcats (21.8% of diet) and have been documented as an important food source for bobcats elsewhere (Rose and Prange 2015, Koehler and Hornocker 1991). Deer were chosen as the representative prey partially because they are a species of great public concern in Ohio, due to difficulties associated with overpopulation. Other prey species populations, like those of rabbits and small rodents, may have also been worthwhile to compare with bobcat presence. Rabbits are consumed most often by bobcats in Ohio (26.4% of diet) and small rodents and insectivores, a group containing many species, is also substantial (32.7% of diet) (Rose and Prange 2015). However, deer are more easily comparable to bobcats with camera trapping data because the cameras were set up to capture animals higher up off the ground. Because of public concern surrounding deer populations, deer abundance in bobcat diet, and the possibly more accurate detection rates using remote cameras, deer were chosen as the prey species for this analysis.

Coyotes, though non-native to the region, are the only present mammalian carnivores that would conceivably compete with bobcats. Coyotes consume many of the same prey species and are capable of killing bobcats (Koehler and Hornocker 1991, Fedriani et al. 2000). The two species of foxes that live in the study region—red foxes and gray foxes—were combined for the analysis of mesopredators. Foxes have been shown to avoid habitats where lynx (*Lynx spp*., of close relation to bobcats) are common and experience declines in reproductive rate after lynx are reintroduced (Fedriani et al. 1999, Helldin et al. 2006). There is growing public concern about declining populations of foxes in Ohio. A strong association between bobcat presence and abundance of any of these species would provide evidence for an effect on the existing animal community due to the reestablishment of bobcats.

Do the data show an association between nocturnal bobcat detection frequency and lunar illumination?

Previous research has demonstrated that numerous species change their nocturnal activity patterns during different phases of the moon (Kronfeld-Schor 2013). Several species of nocturnal birds and rodents, especially those that forage in open environments, avoid moonlight by reducing activity on lit nights (Daly et al. 1992, Mougeot and Bretagnolle 2000). This observation reveals optimal foraging behavior in prey as predation risk for nocturnal prey species increases on moonlit nights (Mougeot and Bretagnolle 2000). Some research has examined the effect that lunar phase has on predators. Coyotes were found to increase territorial vocalizations during the new moon, perhaps due to difficulty visually detecting prey on dark nights (Bender et al. 1996). Maned wolves (*Chrysocyon brachyurus*) decrease distance traveled while hunting under the full moon (Sábato et al. 2006) and African lions (*Panthera leo*) experience reduced food intake during the full moon period (Packer et al. 2011). If these behavioral patterns extend to other predators then bobcats may decrease activity when prey species are less active or less easily captured during high lunar illumination.

One study has examined the impact of lunar cycle and nighttime illumination on bobcat activity using GPS collars in North Carolina (Rockhill et al. 2013). This study found that bobcats *increased* nocturnal foraging activity during the full moon, contrary to the findings conducted on other predatory species. I used nighttime camera detections to test for associations between lunar illumination and bobcat nighttime activity patterns.

MATERIALS AND METHODS

Camera-trapping

All camera-trapping methods used for this project were consistent from 2008 through 2011 and in 2014, following the design described by Prange (2011). Each study site was surveyed using twelve—or ten, for those in 2014—camera stations, each equipped with two remote motion-sensitive cameras, scent lures, and a visual lure (see Figure 2 and Figure 3). Stations were spaced every 500 meters (0.5 km) along or just off of hiking trails, roads, or animal trails in each study site in order to account for the variability of human influence. Bobcats and other large animals regularly use trails to travel, so placing cameras along these high-activity areas typically increases survey success (Sunarto et al. 2013, Heilbrun et al. 2006). All StealthCam cameras were infrared triggered, model 530IR. With ten or twelve stations active, sampling effort at each study site covered five to six kilometers of habitat. Stations were designed to use three trees in a rough triangle—two cameras on two trees, each pointing toward a third scent lure tree. The two cameras were attached to the tree about 0.3 meters off the ground. A scent lure was appropriate due to the rarity of the target animal, but its use limits the types of analyses possible after data collection. Attached to the scent tree was a scent pad: a 4”x4” square of carpet soaked with beaver (*Castor canadensis*) castor oil and a 1”x1” square pouch of dried catnip (*Nepeta cataria*) nailed into the center. The scent pad was placed about 0.3 meters above the ground on the trunk of the tree. In addition to the scent pad, a film canister filled with beaver castor oil was tied higher up (1 meter) above the ground to spread additional scent. A turkey (*Meleagris gallopayo*) feather visual lure was also tied in the same place as the film canister, functioning to attract predatory wildlife with movement. The two-camera design allows researchers to ideally photograph two angles of every animal that visits the scent station and provides a back-up in case one camera fails. Over the data collection period of around two weeks, researchers checked each camera station three times: once to set them up, once to check battery level and functionality a week later, and once to take them down and download pictures.

Data Analysis

Data Documentation. For each photo capture, researchers recorded the species observed (bobcat, deer, squirrel, etc.) as well as the time of day, study site, and camera station within the study site. Trap nights were used as a measure of data collection effort. A trap night was defined as a night in which all cameras were active in a study site. A site with 100 trap nights, for example, would have had all cameras active for 100 days and nights.

Ecological Implications of Bobcat Presence. Using the full camera trap data set available on bobcats in southeastern Ohio, from 2008-2011 and 2014, I examined bobcat distribution, select species correlations, and nocturnal activity patterns.

Distribution

To test the distribution of bobcats in their known range of southeastern Ohio, we used only data from the most heavily trapped study sites. This includes Ale's Run (129 trap nights), Broken ARO (125 nights), Marietta (123 nights), Shawnee (96 nights), and The Wilds (93 nights). The Wilds was included in this analysis in order to increase the sample size and as an interesting comparison. However, this site was camera trapped for only three years (2008, 2009, and 2010), while the other sites were trapped for an additional year (2011). If any important changes in bobcat populations occurred in 2011 it could influence the results and be a cause to doubt comparisons that include The Wilds. It is also a noteworthy site because it is heavily managed for tourism and large areas of the park function as preserves for safari animals (Columbus Zoo and Aquarium 2014). A general linear model (conducted on SPSS Statistics version 22 software) was used to determine differences in bobcat detections between these five sites. The normalized square roots of bobcat detection counts were used as the dependent variable with study site as a fixed factor and number of trap nights as a covariate.

Species Associations

The sites with the greatest number of trap nights were again used, excluding The Wilds due to its highly artificial and managed environment. It was important to control for environment because this question seeks to draw conclusions about bobcat ecology beyond the individual study sites. Associations between three different species (deer, coyotes, and foxes) and bobcats were examined using a binary logistic regression, using SPSS Statistics version 22. For all three analyses, bobcat presence or absence—indicated by "1" or "0"—during each data collection period was the dependent variable. Number of trap nights was a covariate. For the comparisons with coyotes and foxes, the predicting factor was presence ("1") or absence ("0") of the coyotes or foxes. For the comparison with deer, the abundance (scale number) of deer detections was the predicting covariate. The scale number of deer detections could be used for this analysis because deer were present in every study site. Only the presence or absence of the other species was used because bobcats, coyotes, and foxes are much less abundant and were not present in every study site, resulting in zeroes in the data set. Association between species was measured by their co-occurrence in study sites. For example, if coyotes and bobcats are only found in different study sites then there may be evidence of spatial niche separation between the species. If foxes are absent in places where bobcats are present, they may be experiencing additional pressure from bobcat competition and predation. If deer have lower numbers in places where bobcats exist then there may be additional predation pressure on deer.

Lunar Activity Patterns

To examine the activity patterns of bobcats in relation to the lunar cycle, data were organized to relate bobcat photo captures at night—between sunrise and sunset—with day of lunar cycle and percent illumination of the moon. The full data set available was used, spanning all five years. In an effort to maximize the sample size, photo captures within 20 minutes of sunrise or sunset were also included (5 additional captures). All retrospective sunset and sunrise times, as well as percent illumination data, were found at the U.S. Naval Oceanography website, www.usno.navy.mil (Naval Meteorology and Oceanography Command 2015). Some camera stations (half of those at Ale's Run, Marietta, and The Wilds in 2010) were not included in analysis because of audio lures added to those particular scent stations. The camera stations at these sites that did not use audio lures were still included. These audio lure stations were included in the first two analyses on distribution and species associations because the data set used was smaller and benefited from more detections and because Rose and Prange (2015) found no significant effect of the lures on bobcat detection using the same data set. For this analysis, they were removed because the data set used was large enough to allow it. Those sites without bobcat detections at night were also not included in this analysis.

A binary logistic model (on SPSS Statistics version 22) was used to relate bobcat detection (photo capture "1," no capture "0"), study site, and percent illumination. A similar analysis was also done relating day of lunar cycle (1 through 29 or 30) on the night of photo capture with bobcat detections. Lastly, an analysis was conducted relating moon phase—new or full—with bobcat detection. A new or full moon was defined as occurring on the full (100% illumination) or new (0% illumination) moon as well as two nights on either immediate side of the full or new moon. For example, if the moon reached 100% illumination on the 20th, the full moon would be defined as occurring on five nights from the 18th through the 22nd. All three lunar analyses include study site as a factor.

RESULTS

Bobcat Presence Confirmed in New Study Sites

Results from the trapping effort in February and March of 2014 showed presence of bobcats in three study sites in which they had not been scientifically documented previously: Blue Rock State Forest, Tar Hollow State Forest, and Woodbury Wildlife Area (See Map, Figure 1). These three sites were chosen for this most recent trapping season because they exist on the edge of known bobcat range in the state. Tar Hollow and Woodbury had not been previously examined for bobcat presence. Blue Rock had been camera-trapped in 2008, but the effort did not return any photo captures.

Bobcat Ecology

Even though the sampling effort was large and conducted over a large spatial area and several years, the rarity and elusiveness of bobcats in Ohio led to a small sample size of detections (n=91). However, this remains the largest known scientific dataset of bobcat camera detections in the state. The following results are products of this sample and should be read with the knowledge that as more data on state populations of bobcats are produced the analyses may need to be revisited. Confirmation of these results from a larger sample set will enhance the research.

Distribution

The distribution of bobcats across study sites varied. Figure 4 shows the results of a general linear model, summarized by the marginal means of the square root of bobcat detections per site and corrected for number of trap nights (trap night number=29.79). The results show that bobcats were not distributed evenly throughout their range in the state, using Fisher's least significant difference test to determine significance between sites. The abundance differences across all sites were significant (df=4, F=4.43, P=0.018) and some differences between individual sites were significant as well. Differences existed between Broken ARO versus Ale's Run (P=0.003), The Wilds (P=0.004), Marietta (P=0.019), and Shawnee (P=0.031). See Figure 1 for geographical locations of these five sites.

Species Associations

I did not find any significant associations between bobcats and their representative prey or competitor species in the four most heavily trapped study sites. Bobcat presence or absence was not associated with deer abundance (df=2, X^2=0.295, P=0.863). Likewise, bobcats were not associated with coyote presence or absence (df=2, X^2=0.226, P=0.893) or fox presence or absence (df=2, X^2=0.324, P=0.851). See Figures 5, 6, and 7 for co-occurrence between species and Table 4 for a summary of significance between species.

Lunar Activity Patterns

Bobcats were not detected more often during any single day of the lunar cycle, during any period of illumination percentage, or during one phase of the moon. Bobcats were detected on 51 nights out of 604 trap nights included in these analyses, or 8.4% of nights. Although there appears to be a spike in nocturnal activity during both the full moon and the new moon (see Figure 8), I detected no significant effect of lunar cycle on bobcat detection frequency. Associations between bobcat detection and day of lunar cycle were not significant (df=1, X^2=0.057, P=0.812). Associations between bobcat detection and percent illumination of the moon were also not significant (df=1, X^2=0.083, P=0.774). Phases of the moon, defined as simply new or full, showed no significant effect on bobcat detection (df=2, X^2=0.903, P=0.637). 16.9% of trap nights occurred on a full moon and 17.1% of trap nights occurred on a new moon. See Table 5 for a summary of the significance values associated with each analysis.

DISCUSSION

Bobcat detections in Tar Hollow State Park, Blue Rock State Park, and Woodbury Wildlife Area in winter 2014 are evidence of the expansion of bobcat range in Ohio. This is the first known scientific documentation of bobcat presence in these sites. While Tar Hollow and Woodbury were new sites this year, Blue Rock had been surveyed before in 2008 with no record of bobcat presence. Since these three sites were placed on the known edge of bobcat range (see map, Figure 1), these detections indicate that bobcats are expanding their range further into Ohio. The high abundance of bobcats surveyed in these sites likely shows that these are no longer on the fringes of bobcat range. Evidence indicates that the populations surveyed in 2014 were well-established populations. Bobcats are territorial animals and do not naturally occur in high density (Lovallo and Anderson 1996). Some studies on bobcat density estimate only 7 bobcats per 100 km^2 of habitat (Lovallo and Anderson 1996). Achieving photo captures of one or two bobcats per 5 km study site is very successful. I recommend expanding camera trapping even further west to establish the new edge of bobcat range in Ohio. Ideally, cameras could record and monitor these edge populations to better understand how they move into new landscapes, which habitats are better able to support bobcat populations, and the challenges or barriers that may impact migrants. Mammal populations on edges of ranges are typically more vulnerable to environmental pressures, so improved monitoring or management may be necessary to protect growing populations (Yackulic et al. 2011). I am especially interested in the movement of bobcats, which are currently limited to the hilly, rocky, unglaciated region of Ohio, into the flat and more agriculture-intensive central and northwestern regions of the state. The movement of these animals into a novel environment is an opportunity to examine bobcat habitat choice, prey choice, behavior, ability to adapt, and more.

I found significant differences in bobcat abundance between sites, which may suggest that bobcats preferentially inhabit some sites over others. Bobcat detections were observed significantly less frequently at Broken ARO Wildlife Area than at other sites. Broken ARO is not recognizably different from any of the other sites in terms of land use, land history, or topography (see Tables 2 and 3). It is a mid-sized, state-managed area of 3,480 acres and is well within the known bobcat range (Ohio Department of Natural Resources 2015). In the past the area was used for timber harvest and today, though clear cuts still occur, it is used primarily for hunting (Ohio Department of Natural Resources 2015). Both The Wilds Conservation Park and Ale's Run Wildlife Area, the two sites with the highest abundance of bobcats, have a history of surface mining but have been reclaimed as recreational areas (Columbus Zoo and Aquarium 2014, Ohio Department of Natural Resources 2015). Reclaimed mine sites appear to harbor particularly high abundances of bobcats, though that could be for a multitude of reasons. It could be due to preference for the reclaimed mine habitat: generally flattened, with rolling hills and some cliffs. Acidic soil from the past mining operations slows the regrowth of forest in the mined sections but some forest remains in both sites (Columbus Zoo and Aquarium 2014, Ohio Department of Natural Resources 2015). This mixed habitat possibly provides a larger proportion of edge habitat. While male bobcats are known to explore these open areas, females typically avoid them (Lovallo and Anderson 1996). As a species, bobcats usually need at least some forest cover or uneven, rocky terrain to aid in stalking prey (Koehler and Hornocker 1991).

Besides habitat type, there are other factors that could influence bobcat abundance. Variance between study sites may be attributable to prey availability. Bobcat density is dependent on prey biomass (Carbone and Gittleman 2002). A more extensive survey of prey animals, including those species that are not easily captured on camera traps, would be helpful in assessing whether prey are more abundant in areas where bobcats are abundant. Bobcats may also be avoiding sites where humans have a considerable presence. Though data do not exist, to my knowledge, on bobcat encounter frequency with humans in these study sites, it may be worthwhile to examine interactions between bobcats and humans to assess the kind of impact that human activities have on bobcat abundance. The greater abundance of bobcats in eastern sites as opposed to southern sites is of interest, and is consistent with a 2011 report that 67% of bobcat sightings reported to ODNR by the public were in the eastern part of Ohio (Prange 2011). Knowledge of the clustered distribution of bobcats is of great importance for management because it enables conservation efforts to be focused on those areas that have the greatest potential for harboring bobcat populations and areas that have lower bobcat abundance.

The lack of significant species associations in Ohio is an interesting result as it is contradictory to numerous studies that document impacts of predators on competitors, mesopredators, and prey (Estes et al. 2011, Sergio et al. 2014, Hardin 1960, Prugh et al. 2009, Ritchie and Johnson 2009). These results may be attributable to several factors. First, there may indeed be no substantial effect on the animal community. Coyotes have been occupying the top predator niche for many years in the absence of native mammalian Ohio predators. It is possible that coyotes have been exerting top-down control on prey species and mesopredator species so that the reestablishment of bobcats does not have a novel impact on the community. Coyotes can limit fox habitat use and kill foxes in areas where they share habitat (Harrison et al. 1989, Fedriani et al. 2000). Coyotes, however, were less likely to be detected than bobcats in almost all study sites from this report (see Figure 6) and therefore may actually have a smaller effect on lower trophic levels than more abundant predators like bobcats.

There may also be little competition at all between predators and mesopredators due to the abundance of prey species available for bobcats, coyotes, and foxes. When resource availability is high and competition is low, there may be reduced effects from one predator to another predator or to a mesopredator (Ritchie and Johnson 2009). Similarly, if there is sufficient niche separation in food choice, fewer effects will be detected between competitors (Ritchie and Johnson 2009). While bobcats and coyotes have comparable diets, the proportion of prey species consumed differs (Koehler and Hornocker 1991). Both species prey heavily upon small rodents, rabbits, and deer (Koehler and Hornocker 1991, Rose and Prange 2015). Coyotes, however, eat a wider range of prey types and scavenge much more (Koehler and Hornocker 1991). Koehler and Hornocker (1991) found that coyotes scavenged on 79% of available deer carcasses and bobcats on only 5%. Another consideration is that physical size of bobcats did not allow the animals to have a large effect on other species. Delong et al. (2015) found that trophic cascades are weaker when the body size of the top predator is smaller. We may not see bobcats strongly influencing community structure because they are mid-sized as opposed to large predators.

Alternatively, it is possible that top-down effects of bobcat presence in these sites were undetectable using this method. More camera trapping, or some other kind of survey, should be implemented on the current edge of bobcat range to better understand initial effects of bobcat presence on the community, if such effects exist. It may also be useful to camera trap in sites without any bobcat presence. All four sites used here were chosen due to suspected or known bobcat occupation. Sites that have no reports of bobcat sightings could serve as controls against which to compare these results. Detecting such effects is important to fully understand species interactions, inform wildlife management, and to confirm or contradict current hypotheses in the larger predator ecology context.

I did not find significant effects of any measure of the lunar cycle and bobcat detections, in contrast to the findings of Rockhill et al. (2013). Rockhill et al. used GPS collars on seven bobcats in North Carolina to estimate activity levels during varying lunar illumination and during moon phases. They found increased nocturnal activity during periods of 10-50% lunar illumination and relatively higher activity during the full moon (five days surrounding 100% illumination) than the new moon (five days surrounding 0% illumination). My research found no statistical evidence to support these findings. I first tested percent illumination in association with bobcat detections, then day of the lunar cycle (1 through 29 or 30) to account for possible waning and waxing differences. Lastly, I categorized the illumination values into full and new moon periods, consistent with the methods of Rockhill et al. (2013). I obtained insignificant values for all three analyses (see Table 5).

Despite the lack of statistical evidence in my results, there is an apparent spike in detection frequency of Ohio bobcats during the full and the new moon with less activity between these peaks (see Figure 8). These spikes may reflect real patterns or they may be chance occurrences related to the number of trap nights per phase. The benefit of camera traps is that they can often achieve a greater (though still not great) sample size (n=55 nighttime photo detections); the benefit of GPS tracking is that it monitors individual animals continuously. Both methods are beneficial to the study of bobcat ecology, though neither is ideal. Further research should be done to elucidate any associations that may exist between lunar cycle and bobcat activity. This research can often be done retroactively, using camera surveys or other research methods that have already been conducted. Data sets could (and should) be pooled between research projects to maximize sample size for a rare species.

Now, with the re-expansion of several North American predators, we are at a pivotal time in natural history where we have the opportunity to study the upper trophic level in areas where top predators have been absent for years. While ecologists have largely studied the effects on plant and animal communities due to the absence of predators, we are now able to study those same communities in the presence of their native predators. We are able to accurately compare ecosystems with and without intact food webs, thus ultimately testing the hypotheses and ideas formed from research on disparate, manipulated ecosystems. We can make observations on temporally long and spatially large scales in real ecosystems. What effects may occur when these predators return after such a long absence? How will predators choose their habitats? Will plant and animal communities return to a relatively undisturbed state, or will the repopulation just be another disturbance in a long list of recent (anthropogenic) disturbances? It is important to study and answer these questions now while these changes are occurring in real time, in real ecosystems.

Conclusions

The results from this research may have a meaningful impact on Ohio bobcat management. Bobcats are no longer a protected species under the Endangered Species Act in Ohio as of spring

2014 and therefore may be more vulnerable to human interference as they repopulate Ohio habitat. It will soon be important to examine ways in which the people of Ohio and predators can coexist and to engage in public outreach to facilitate their reestablishment across the landscape. As bobcats begin to reestablish, first in the southeast but hopefully throughout the state, it is crucial that we monitor their movements, understand their ecology, and make the most informed decisions possible for population management.

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TABLES AND FIGURES

Study Site	Trap Nights	2008	2009	2010	2011	2014
Ale's Run	129 *(27)*	19 *(6)*	30 *(2)*	44 *(9)*	36 *(10)*	0 *(0)*
Blue Rock	28 *(4)*	14 *(0)*	0 *(0)*	0 *(0)*	0 *(0)*	14 *(4)*
Broken ARO	125 *(6)*	20 *(0)*	25 *(1)*	47 *(4)*	33 *(1)*	0 *(0)*
Egypt Valley	17 *(0)*	17 *(0)*	0 *(0)*	0 *(0)*	0 *(0)*	0 *(0)*
Ironton	15 *(0)*	15 *(0)*	0 *(0)*	0 *(0)*	0 *(0)*	0 *(0)*
Lake Katharine	16 *(0)*	16 *(0)*	0 *(0)*	0 *(0)*	0 *(0)*	0 *(0)*
Marietta	123 *(18)*	16 *(1)*	28 *(4)*	49 *(7)*	30 *(6)*	0 *(0)*
Salt Fork	16 *(0)*	16 *(0)*	0 *(0)*	0 *(0)*	0 *(0)*	0 *(0)*
Shawnee	96 *(14)*	13 *(2)*	26 *(0)*	38 *(8)*	30 *(4)*	0 *(0)*
Tar Hollow	14 *(1)*	0 *(0)*	0 *(0)*	0 *(0)*	0 *(0)*	14 *(1)*
Wildcat Hollow	15 *(0)*	15 *(0)*	0 *(0)*	0 *(0)*	0 *(0)*	0 *(0)*
Wayne National Forest	17 *(0)*	17 *(0)*	0 *(0)*	0 *(0)*	0 *(0)*	0 *(0)*
Woodbury	14 *(1)*	0 *(0)*	0 *(0)*	0 *(0)*	0 *(0)*	14 *(1)*
The Wilds	93 *(20)*	15 *(3)*	32 *(5)*	46 *(12)*	0 *(0)*	0 *(0)*
Grand total	**718** *(91)*	**193** *(12)*	**130** *(12)*	**224** *(40)*	**129** *(21)*	**42** *(6)*

Table 1. Summary of dataset from camera trapping in 14 sites in southeastern Ohio. Columns show total trap nights and trap nights in each of five years. Italicized numbers in parentheses indicate the number of bobcat detections corresponding with each trapping effort.

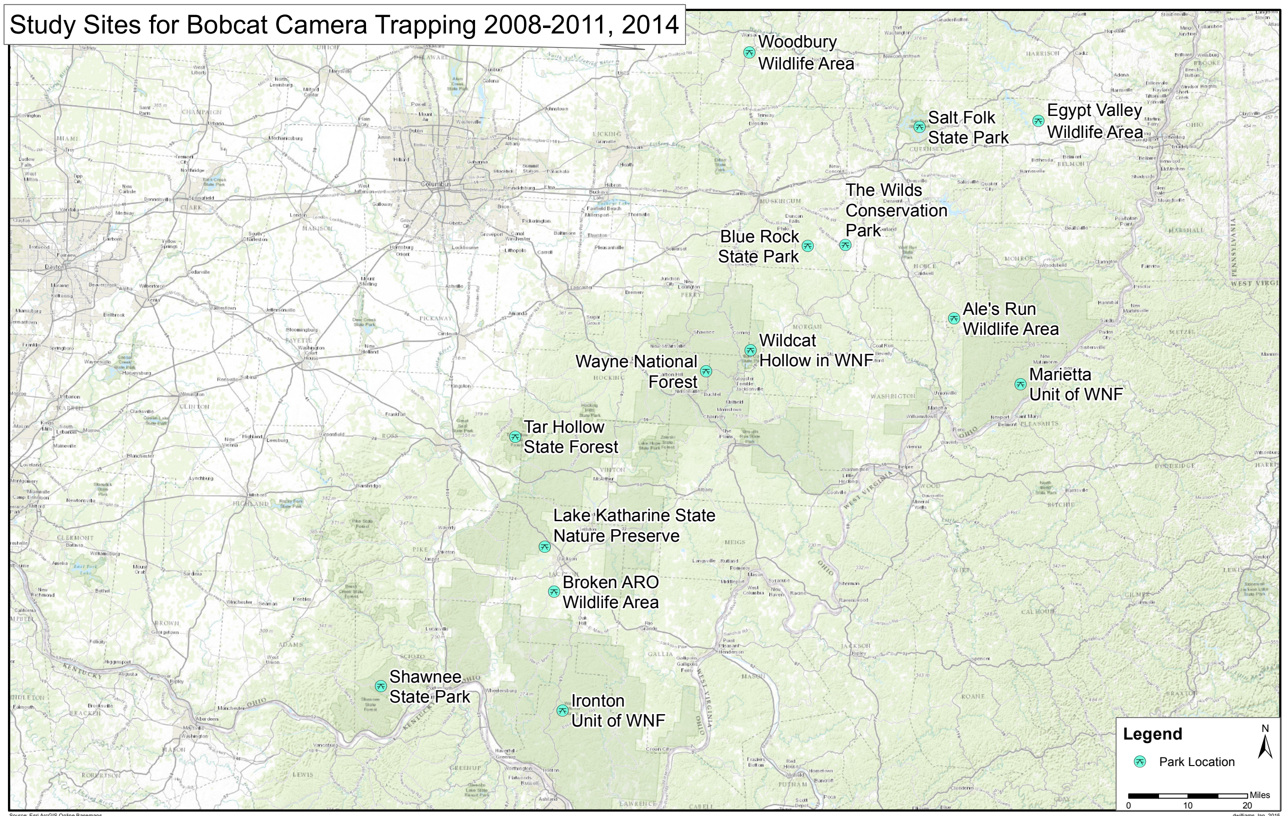

Fig. 1. Map of all study sites, overlaid on Esri ArcGIS Online Basemap. Created by Andrew G. Williams, 2015.

Study Site	Forest Type	Size (Acres)	County	Latitude / Longitude
Ale's Run	Wildlife Area	2,905	Noble	N 39° 63' 86.19", W 81° 38' 47.66"
Blue Rock	State Park	322	Muskingum	N 39° 48' 58.97", W 81° 50' 55.79"
Broken ARO	Wildlife Area	3,480	Jackson	N 39° 3' 15.66", W 82° 29' 14.41"
Egypt Valley	Wildlife Area	18,011	Belmont	N 40° 5' 22.68", W 81° 10' 49.00"
Ironton	National Forest	99,049 (discontinuous)	Lawrence	N 38° 36' 33.00", W 82° 38' 55.00"
Lake Katharine	State Nature Preserve	2,019	Jackson	N 39º 05’ 9.48”, W 82º 40’ 2.92”
Marietta	National Forest	63,381 (discontinuous)	Washington	N 39° 21' 52.18", W 81° 23' 30.00"
Salt Fork	State Park	17,229	Guernsey	N 40° 7' 0.98", W 81° 29' 36.57"
Shawnee	State Park	63,000	Scioto	N 38° 43' 46.01", W 83° 13' 44.36"
Tar Hollow	State Park	604	Hocking	N 39° 21' 53.38", W 82° 46' 9.40"
Wildcat Hollow	Wildlife Area	49,000	Morgan	N 39° 34' 23.32", W 84° 44' 36.19"
Wayne	National Forest	67,224 (discontinuous)	Athens	N 39° 24' 9.38", W 81° 10' 0.24"
Woodbury	Wildlife Area	19,246	Coshocton	N 40° 17' 11.16", W 82° 1' 47.88"
The Wilds	Conservation Park	9,154	Muskingum	N 39° 49’ 32.56”, W 81° 44’ 51.49”

Table 2. Summary of study sites as described by state, national, and private management (USDA Forest Service 2015, Ohio Department of Natural Resources 2015, Columbus Zoo and Aquarium 2014).

Study Site	Land History	Current Land Use	Habitat Types	Topography
Ale's Run	mining	hunting, trapping, recreation	forested, brushland	rugged, steep
Blue Rock	mining, farming	hunting, horse riding, recreation	forested	rugged, steep
Broken ARO	logging	logging, hunting, recreation	forested, clear cuts	steep, rocky, hilly
Egypt Valley	mining, logging	hunting, trapping, recreation	forested, grassland, brushland	steep, hilly
Ironton	oil and gas, mining, farming, logging	logging, oil and gas, hunting, ATVs, recreation	forested, clear cuts, human habitation	rugged, hilly
Lake Katharine	dam	recreation, research	forested	cliffy, steep
Marietta	oil and gas, mining, farming, logging	logging, oil and gas, hunting, horse riding, recreation	forested, clear cuts	rugged, hilly
Salt Fork	dam, mining	hunting, horse riding, snowmobiling, golf, recreation	forested, grassland	steep, hilly, caves
Shawnee	game preserve	hunting, horse riding, golf, recreation	forested	hilly, valleys
Tar Hollow	farming	hunting, horse riding, mountain biking, recreation	forested	rugged, steep
Wildcat Hollow	oil and gas, farming	hunting, recreation	forested, crop fields, brushland	rugged, hilly
Wayne	oil and gas, mining, farming, logging	logging, oil and gas, hunting, horse riding, ATVs, recreation	forested, clear cuts, human habitation	rugged, hilly
Woodbury	mining, game preserve	hunting, recreation	forested, brushland, human habitation	rugged, hilly
The Wilds	mining	hunting, recreation	forested, grassland	hilly

Table 3. Summary of study site environments as described by state, national, and private management (USDA Forest Service 2015, Ohio Department of Natural Resources 2015, Columbus Zoo and Aquarium 2014).

Fig. 2. Example of the scent and visual lure design at a camera station. A turkey feather and a film canister of beaver castor hang from a branch above the scent tree to catch the attention of passing wildlife. A scent lure (beaver castor and catnip) is nailed into the base of the tree about .3 meters above the ground. Two cameras (see Figure 3) are aimed at this tree to form a triangle.

Fig. 3. One of two StealthCam cameras at a station in Tar Hollow. Both cameras were angled to face the lures on a third tree.

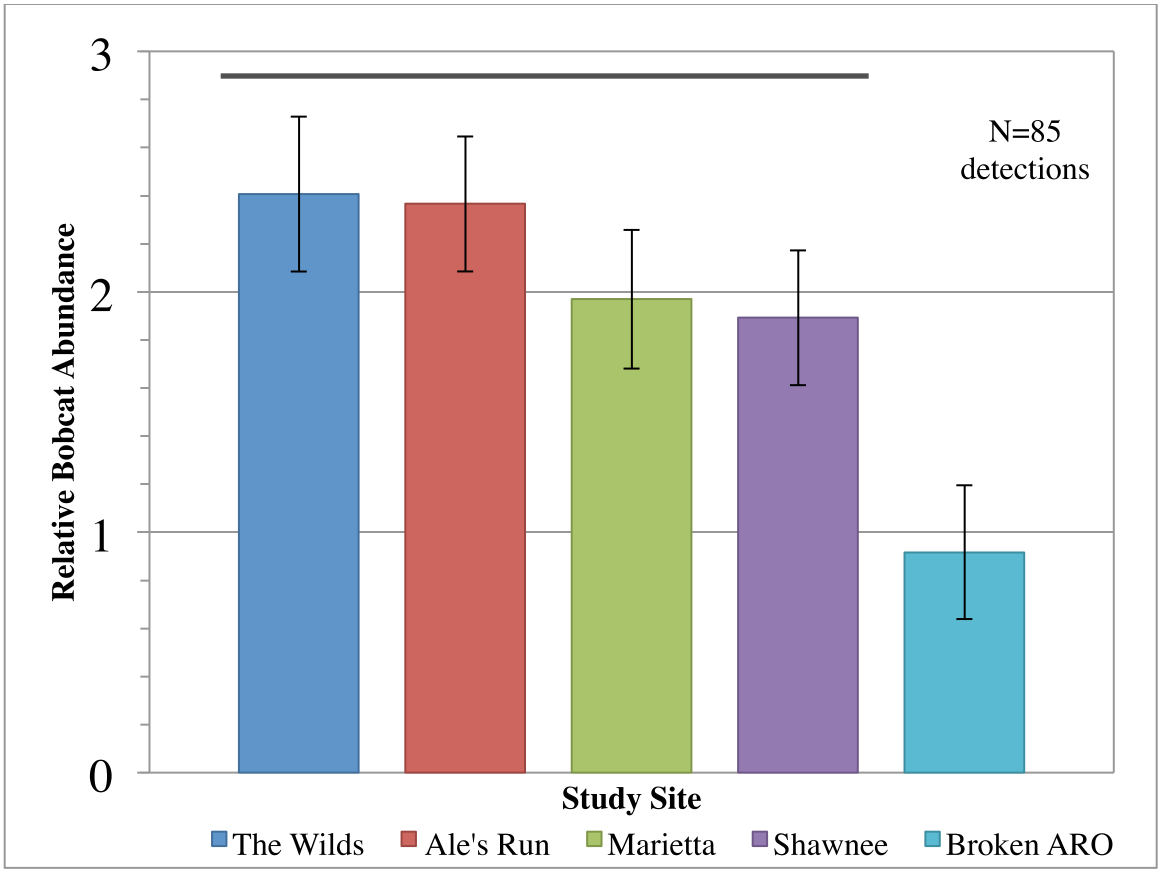

Fig. 4. Relative bobcat abundance at each of five sites. Relative bobcat abundance is measured by the marginal means of the normalized square roots of bobcat detections at each site, with the number of trap nights as a covariate. Error bars show standard error and the line above columns indicates no significant differences. Broken ARO differs significantly from all four other sites (P<0.05). See Figure 1 for a map of these sites and Table 1 for sample size N at each site. Overall, all five sites were significantly variable (P=0.018) indicating a nonrandom distribution of bobcats within surveyed sites.

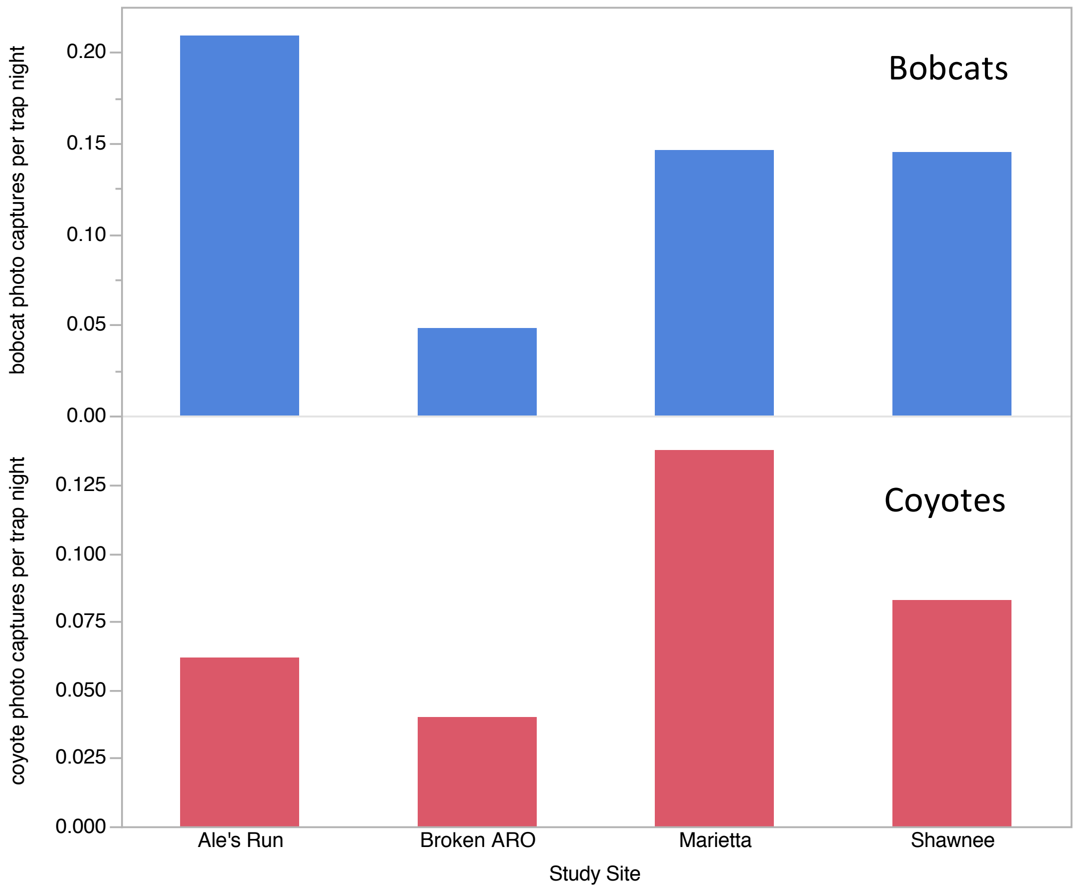

Fig. 5. Relative abundance (photo captures per trap night) of bobcats and coyotes in the four most heavily trapped sites (nights>95), excluding The Wilds. The greatest difference exists in Ale's Run Wildlife Area. Notice the different x-axis scales to account for absolute abundance of species.

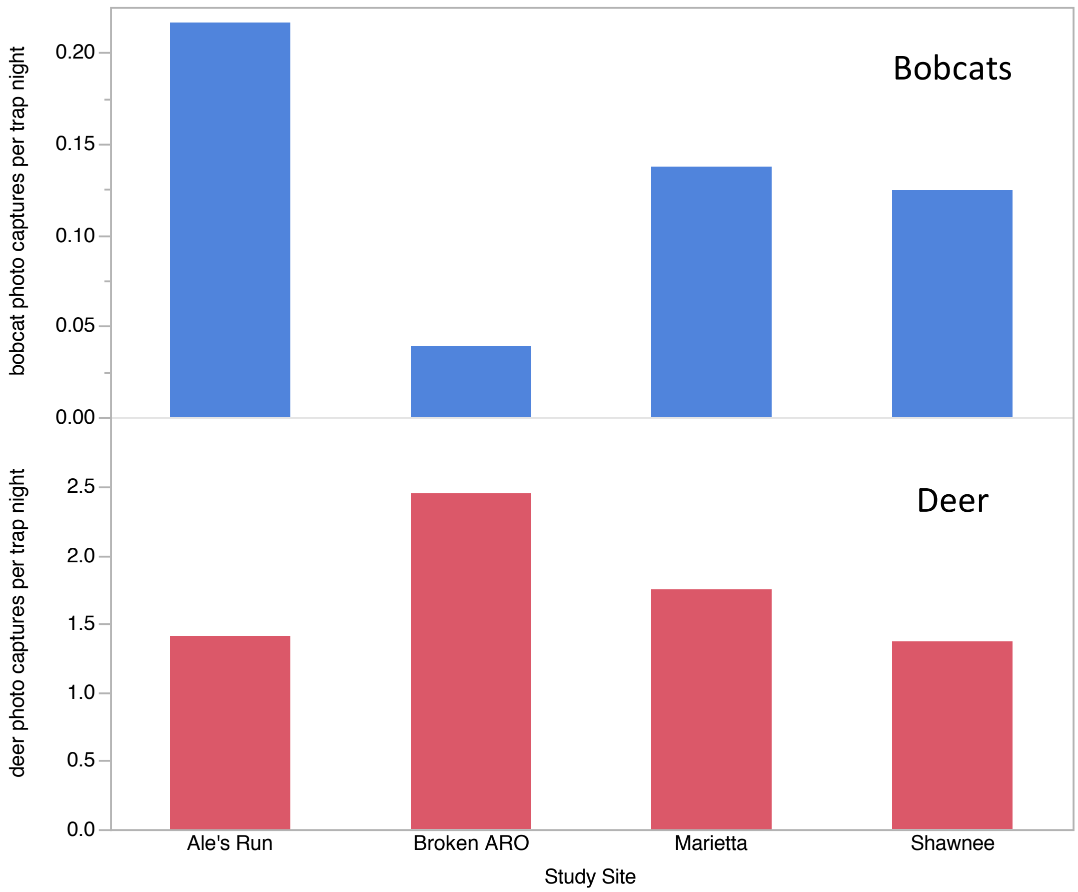

Fig. 6. Relative abundance (photo captures per trap night) of bobcats and deer in the four most heavily trapped sites (nights>95), excluding The Wilds. Deer are most abundant in Broken ARO, while bobcats are least abundant in the same site. Deer are least abundant in Ale's Run, where bobcats are most abundant. Notice the different x-axis scales to account for absolute abundance of species.

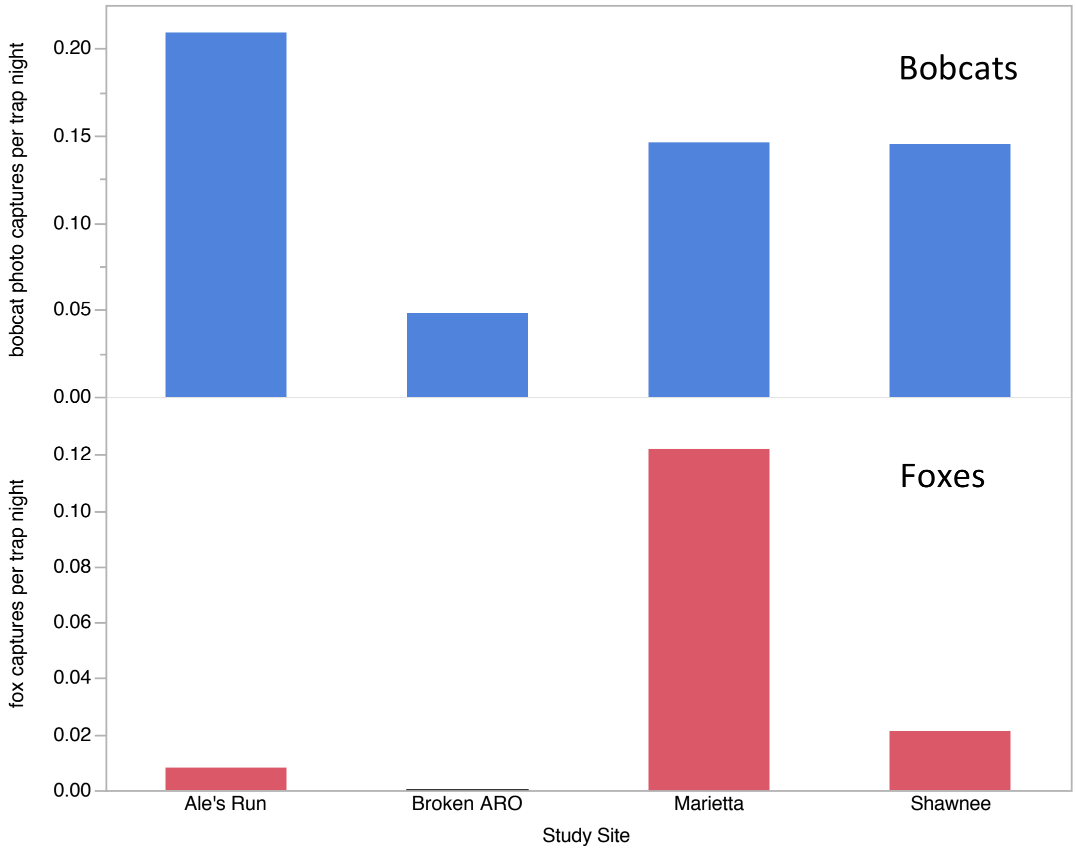

Fig. 7. Relative abundance (photo captures per trap night) of bobcats and foxes in the four most heavily trapped sites (nights>95), excluding The Wilds. Foxes are least abundant in Broken ARO, similar to bobcats. Bobcats, however, are very abundant in Ale's Run while foxes are not relative to their populations in Marietta. Notice the different x-axis scales to account for absolute abundance of species.

Species	Community Role	Association Significance
White-Tailed Deer *Odocoileus virginianus*	Prey	*P*=0.863
Coyote *Canis latrans*	Predator	*P*=0.893
Fox *Vulpes vulpes* and *Urocyon cinereoargenteus*	Mesopredator	*P*=0.851

Table 4. Summary of significance values resulting from a binary logistic regression analysis, associating presence or absence of bobcats with detections of select other species.

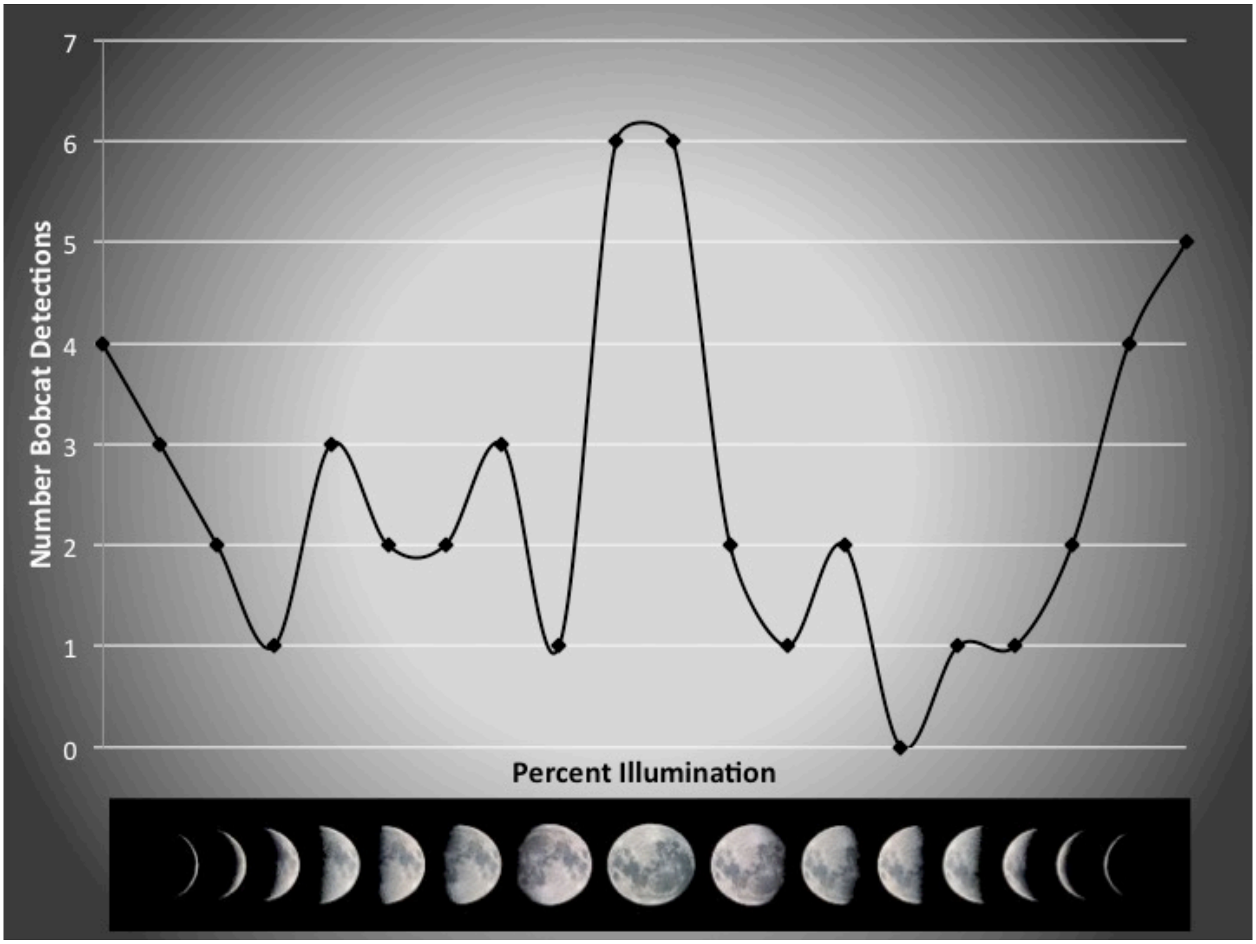

Fig. 8. Nocturnal bobcat detections recorded through the full lunar cycle. Illumination proceeds from 0% illumination on the left to 0% illumination on the right, with 100% in the center. 60% of bobcat detections occurred at night, n=55. This figure uses binary detections ("1" for presence in a single night) where n=51. It does not control for sampling bias, if there is any.

Test Type	**Significance Value**
New or Full Moon	P=0.637
Percent Illumination	P=0.774
Day of Cycle	P=0.812

Table 5. Summary of significance values from the three analyses conducted to test for an association between bobcat activity and lunar illumination.

Fig. 9. Photo capture of a bobcat in Blue Rock State Park, February 2014.

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